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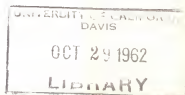
Division of Agricultural Sciences

UNIVERSITY OF CALIFORNIA

SOME CHARACTERISTICS OF FARM IRRIGATION WATER SUPPLIES IN THE SAN JOAQUIN VALLEY

Charles V. Moore

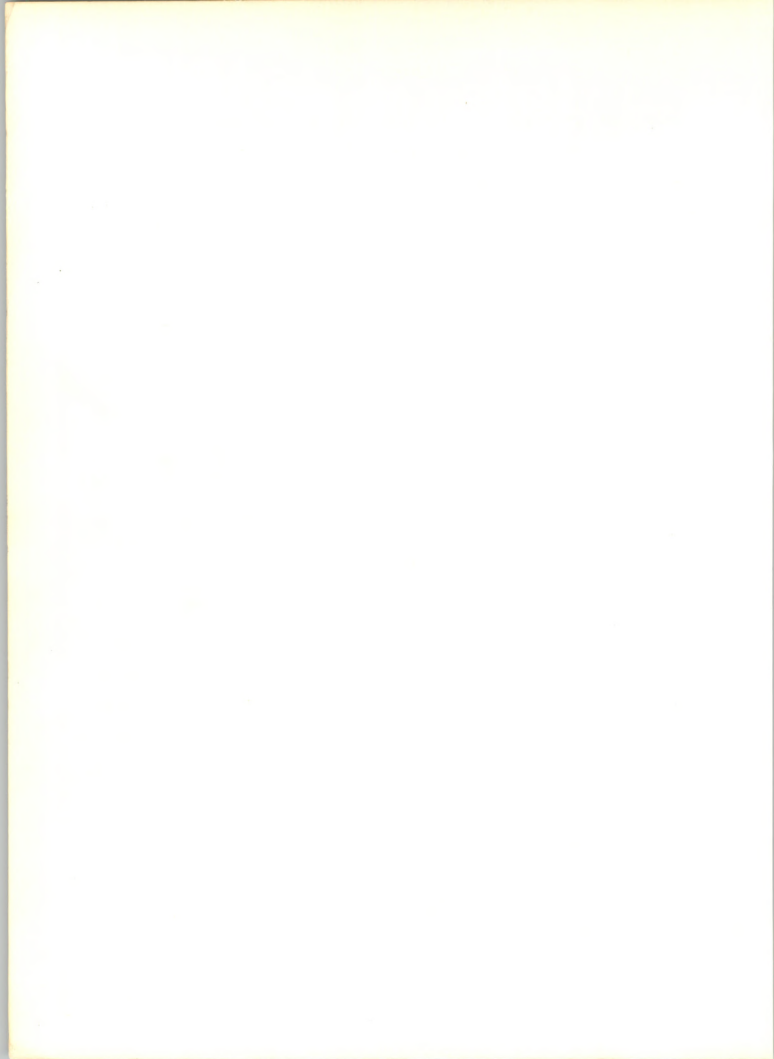
Trimble R. Hedges



**CALIFORNIA AGRICULTURAL EXPERIMENT STATION
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS**

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FOREWORD

This report grew out of a broad study of on-farm irrigation under the California Agricultural Experiment Station Project Numbers 1641 and H-1863. Titles of these projects indicate their objectives and subject matter; Economics of Adjustments on California Cotton Farms, and Effects of On-Farm Irrigation Water Supplies and Costs on Cropping Systems and Production Adjustments. Analytical results from studies under these projects appear elsewhere. These analyses involved a great deal of data, some of which we drew from secondary sources; other parts of which represented primary data, although we may have obtained even this information through the cooperation of some other agency. But much of this factual information has value for uses beyond the scope of these original studies, and should be made available in a form suitable for such uses. This is the purpose of the present report; it brings together in convenient form a wide range of information on both ground water and surface sources in the San Joaquin Valley. Some of this information appears in tabular form, other portions are mapped. Parts are fairly complete for given areas, other parts represent a sampling.

We are indebted to many agencies and individuals without whose generous cooperation neither this report nor the more analytical studies, supported in part by these data, would have been possible. Among these we can list only a few of those upon whom we relied most heavily. The major power companies serving the San Joaquin Valley, Pacific Gas and Electric, and Southern California Edison, authorized us to use well test data previously released to the United States Geological Survey. The latter agency also aided greatly in this procedure by making photostatic copies from office records. The California Regional Water Pollution Control Board made well driller reports available to us (data for individual reports are not identified in order to keep both of these sets of

information confidential). The California Department of Water Resources also assisted greatly in these studies by making maps, reports, and other information available, as did the United States Bureau of Reclamation. The California Irrigation Districts Association, many individual irrigation districts, and various manufacturers and distributors of irrigation pumps and equipment provided much valuable assistance in the form of factual data and interpretation. We, of course, drew heavily on published reports and releases of the agencies named here, plus many others.

Among the many individuals to whom we owe appreciation, we wish to mention particularly Messrs. R. S. Ayers, Wm. Balch, D. E. Butler, J. S. Gorlinski, E. J. Griffith, H. H. Holley, G. V. Hufford, J. M. Ingles, F. Manz, B. M. Smith, H. M. Stafford, S. T. Stairs, I. Stennett, and H. D. Wilson. A complete list would extend to a much greater length; we stop at this point only because of space limitations.

As indicated above, this report resulted from studies under two Experiment Station projects. The University of California Water Resources Center contributed an important fraction of the funds used in financing these studies, through its grants for research under Project H-1863.

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SOME CHARACTERISTICS OF FARM IRRIGATION WATER SUPPLIES IN THE SAN JOAQUIN VALLEY

Charles V. Moore and Trimble R. Hedges^{1/}

INTRODUCTION

Wide differences in irrigation water supplies and costs characterize the San Joaquin Valley. These differences react strongly on cropping programs and farming systems and practices, and, consequently, on farm earnings and profits. Any studies concerned with farm firms in this area, either individually or in the aggregate, must consider both the physical and economic characteristics of irrigation water. Facts about water supplies and cost elements are essential for this purpose.

OBJECTIVE

The objective of this report is to assemble and present in convenient form both physical and economic data related to irrigation water supplies and cost in the San Joaquin Valley. It includes information for both surface and ground water sources.^{2/}

CHARACTERISTICS OF THE STUDY AREA

The San Joaquin Valley in California is bounded on the north by the Sacramento-San Joaquin Delta, on the south by the San Emigdio and Tehachapi mountains, on the east by the Sierra Nevadas, and on the west by the Coastal Range. Climate in this area varies from arid in the south to semiarid at the

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^{2/} Portions of these data appeared earlier in California Agriculture, published by these same authors. "Irrigation Pumping Plant Characteristics in the San Joaquin Valley," Vol. 13, No. 8, August 1960; "Irrigation Costs of Pumping in the San Joaquin Valley," Vol. 8, No. 10, October 1960; and "Surface Water Deliveries and Costs in the San Joaquin Valley Cotton Area," Vol. 15, No. 3, March 1961.

northern extremes, with average annual rainfall diminishing from northeast to southwest. The longtime average precipitation for Modesto in the northern part of the Valley is 14.11 inches per year; Bakersfield, at the southern end, has an annual average of 6.91 inches.^{1/} The western portion of the Valley located in the rainshadow of the Coastal Range is drier than Eastside. Average annual rainfall at Huron in western Fresno County is 5.80 inches while the annual average at Visalia in Eastside is 9.45 inches.

The above rainfall pattern has considerable influence on local irrigation water supplies, including both ground and surface sources. Precipitation is not important as a direct source of water for summer crop production. Its seasonal and year-to-year variations, however, critically affect stream runoff in the mountains and recharge of the underground water basin from which farmers pump well water.

Climatic conditions, other than precipitation, in certain parts of the Valley produce an ideal environment for growing certain crops and fruits. Irrigation makes such production possible, and these crops have tended to concentrate in these localities.

The soils of the Valley are primarily recent alluvium, with some lake basin soils. Some of these soils, depending upon how and when they were deposited, contain such high concentrations of calcium and sodium that they are unproductive for agriculture.

Fruit, nut, and vine production is concentrated east of the Valley trough on a north-south axis. This subarea includes 36 percent of the state's total fruits and nuts acreage.

Almost all San Joaquin Valley cotton production occurs south of the southern border of Merced County. Mean daily temperatures north of this line are too low for profitable commercial cotton production.

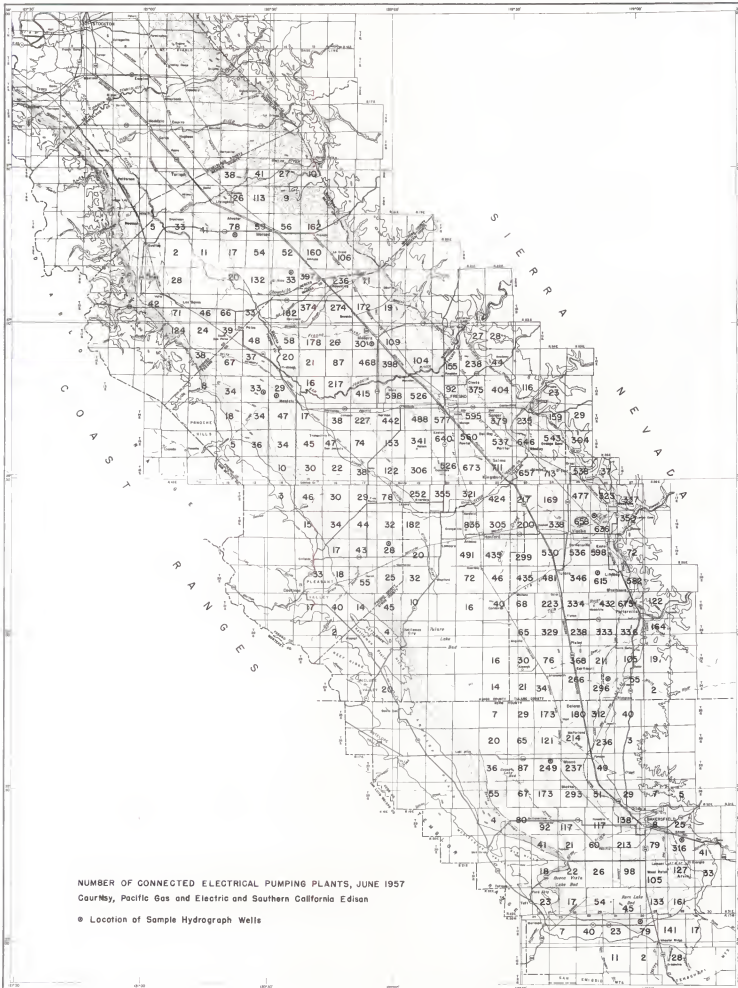
^{1/} Calculated by the authors from United States Weather Bureau reports.

The supply and development of irrigation water influences farm size in the Valley. Farming first developed along the Eastside with small farms predominating, as they still do, in this subarea. Limited water supplies available from streams, and the inability of settlers to finance larger farms, dictated these small operations. Land-development companies originally owned much of the land on the Eastside; they in turn sold it to settlers. These companies subdivided their sizable tracts into small parcels for quick sale. As land development continued streams were no longer adequate as a dependable source of water for summer irrigation. Conservation storage dams on some of these streams were too costly for local groups to finance. In 1902, with the passage of the Reclamation Act, help became available from the Federal Government. Along with Federal aid, however, came the "160-acre limitation." The results were to ration the supply of surface water among users; and greatly to decrease the opportunity for farmers to expand farm size in this subarea.

Large scale development in the western and southern portions of the San Joaquin Valley did not occur until after World War II. At this time, the deep well turbine pump, and relatively high cotton prices, made it economically feasible to lift water from deep underground reservoirs for irrigation (see Figure 1). Capital and acreage limitations did not restrict development in these areas; extremely large-sized farms, therefore, are characteristic here.

Physical Characteristics of Irrigation Pumps and Wells

The major electrical power companies serving the San Joaquin Valley test customers' pumps without charge. This analysis uses the results from 11,000 such tests, ranging from Stockton to south of Bakersfield, during the period 1949-54



(see Figure 2). Data available for each pumping plant test include the plate and input horsepower, static depth, pumping depth, and total lift, as well as pump discharge in gallons per minute and temperature.^{1/} From these data, the power companies calculated over-all plant efficiency, drawdown, kilowatt-hours per acre-foot, and specific capacity of the pumping plant.

Arithmetic means for some of these characteristics, by geographic townships, are available; we present these data in Table 1.

The information in Table 1 indicates considerable variation in pumping plant characteristics even from as small a geographic area as one township to the next. These results are reinforced by interviews with well drillers, farmers, and pump company personnel working in the San Joaquin Valley.

Total pumping lifts are smallest in the northeastern part of the Valley and tend to increase from east to west and from north to south following fairly closely the annual rainfall pattern.

We considered the number of pump tests per township adequate for most purposes except in the Tulare Lake basin area. Here the large farming corporations test their own wells, thus sharply limiting the number of power company tests, and hence, the information available to us.

^{1/} Definitions for terms used in this section are as follows:

Static depth - distance from the center of the pump head to the surface of water in the well when the pump is not operating.

Pumping depth - distance from the center of the pump head to the surface of water in the well when the pump is operating.

Total lift - distance or pressure measured in feet from the center of the discharge pipe to the water level when the pump is operating.

Input horsepower - kilowatt input divided by .746.

Over-all plant efficiency - motor efficiency multiplied by pump efficiency.

Drawdown - difference between static lift and pumping lift.

Kilowatt-hours per acre-foot - are determined by the formula:

$$\frac{1.024 \times \text{total lift}}{\text{over-all plant efficiency}}$$

Specific capacity - represents $\frac{\text{g.p.m.}}{\text{drawdown}}$

Plate horsepower - is the manufacturer's horsepower rating.

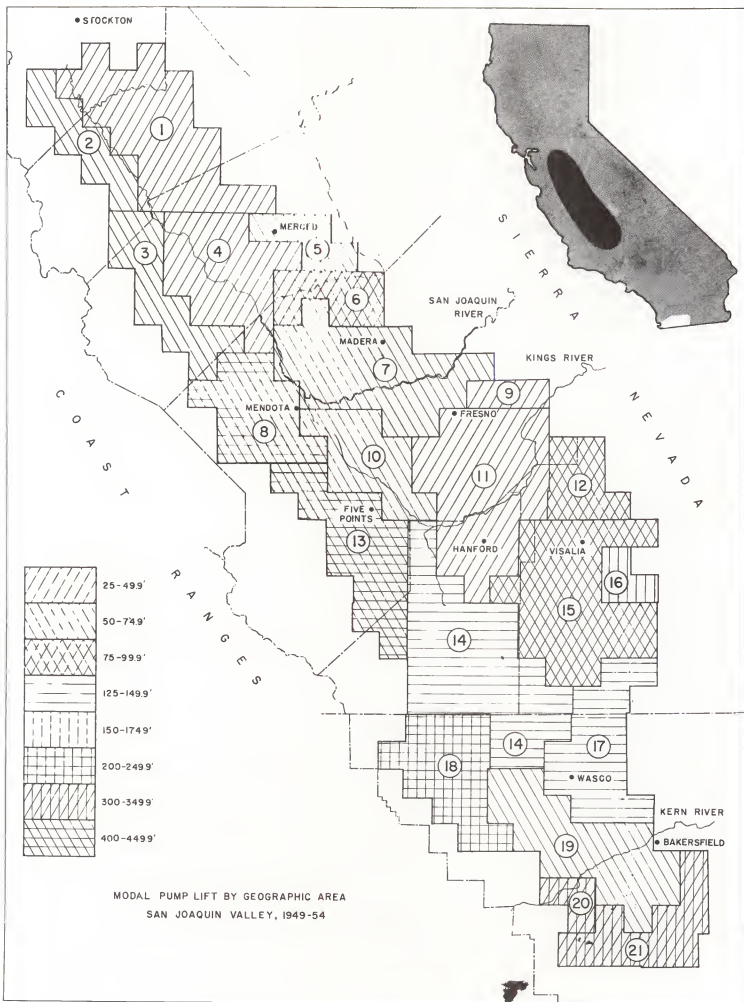


TABLE 1

Mean Pumping Plant Characteristics by Township San Joaquin Valley, 1949-59

Township	Number of tests	Plate horse-power	Static depth	Pump depth	Draw-down	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Township	Number of tests	Plate horse-power	Static depth	Pump depth	Draw-down	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency
(W. Diablo Main Division)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
T12																			
R11	27	152.8	231.4	307.9	30.6	310.7	1863.7	589.9	60.6	R12	27	152.8	231.4	307.9	30.6	310.7	1863.7	589.9	60.6
R13	13	118.1	208.3	283.4	36.2	271.4	1305.5	514.4	53.4	R13	13	118.1	208.3	283.4	36.2	271.4	1305.5	514.4	53.4
R14	2	62.5	25.0	68.8	36.2	64.8	263.0	17.2	49.5	R14	2	62.5	25.0	68.8	36.2	64.8	263.0	17.2	49.5
R15	14	31.7	34.3	56.6	16.6	59.0	140.8	25.9	53.7	R15	14	31.7	34.3	56.6	16.6	59.0	140.8	25.9	53.7
R16	3	63.0	81.3	96.6	13.0	81.0	253.0	10.7	57.5	R16	3	63.0	81.3	96.6	13.0	81.0	253.0	10.7	57.5
R17	99	29.4	67.0	80.1	19.3	81.7	61.7	16.8	58.4	R17	99	29.4	67.0	80.1	19.3	81.7	61.7	16.8	58.4
R18	36	20.8	77.1	86.2	9.1	88.0	61.7	16.8	58.4	R18	36	20.8	77.1	86.2	9.1	88.0	61.7	16.8	58.4
R19	38	22.8	72.5	85.0	12.5	88.5	763.2	156.8	50.1	R19	38	22.8	72.5	85.0	12.5	88.5	763.2	156.8	50.1
R20	38	13.8	49.2	15.5	61.7	68.6	125.8	50.1	52.1	R20	38	13.8	49.2	15.5	61.7	68.6	125.8	50.1	52.1
R21	57	11.5	11.4	60.1	15.4	69.9	238.0	148.1	46.8	R21	57	11.5	11.4	60.1	15.4	69.9	238.0	148.1	46.8
R22	1	6.5	44.2	64.4	31.8	68.8	284.1	164.6	45.6	R22	1	6.5	44.2	64.4	31.8	68.8	284.1	164.6	45.6
R23	1	9.9	31.7	55.6	22.3	69.8	284.1	164.6	45.6	R23	1	9.9	31.7	55.6	22.3	69.8	284.1	164.6	45.6
T13																			
R11	1	150.0	--	94.0	--	94.5	1006.0	864.7	64.0	R12	26	232.9	365.7	435.0	41.4	399.5	1024.2	737.4	57.9
R12	26	232.9	365.7	435.0	41.4	399.5	1024.2	737.4	57.9	R13	23	138.0	397.2	450.0	40.4	380.4	1024.2	737.4	57.9
R13	23	138.0	397.2	450.0	40.4	380.4	1024.2	737.4	57.9	R14	15	50.7	211.4	201.4	40.0	201.4	1024.2	737.4	57.9
R14	15	50.7	211.4	201.4	40.0	201.4	1024.2	737.4	57.9	R15	35	37.9	47.7	57.7	19.9	69.9	165.5	112.5	62.7
R15	35	37.9	47.7	57.7	19.9	69.9	165.5	112.5	62.7	R16	36	37.9	47.7	57.7	19.9	69.9	165.5	112.5	62.7
R16	36	37.9	47.7	57.7	19.9	69.9	165.5	112.5	62.7	R17	69	18.5	43.4	59.3	15.4	61.0	87.0	113.0	55.1
R17	69	18.5	43.4	59.3	15.4	61.0	87.0	113.0	55.1	R18	44	13.2	40.6	41.6	9.9	56.8	97.1	43.4	43.4
R18	44	13.2	40.6	41.6	9.9	56.8	97.1	43.4	43.4	R19	39	10.4	47.5	25.7	8.1	39.0	438.1	123.0	49.8
R19	39	10.4	47.5	25.7	8.1	39.0	438.1	123.0	49.8	R20	59	22.4	41.9	51.9	9.8	61.1	747.3	135.2	49.5
R20	59	22.4	41.9	51.9	9.8	61.1	747.3	135.2	49.5	R21	112	11.3	29.3	42.3	16.5	53.0	125.0	50.2	50.2
R21	112	11.3	29.3	42.3	16.5	53.0	125.0	50.2	50.2	R22	65	9.4	29.5	44.2	48.2	49.6	113.9	46.3	46.3
R22	65	9.4	29.5	44.2	48.2	49.6	113.9	46.3	46.3	R23	7	5.4	3.3	41.9	23.6	46.9	149.0	150.0	32.9
R23	7	5.4	3.3	41.9	23.6	46.9	149.0	150.0	32.9	T14									
R12	24	210.7	499.9	519.3	30.2	555.8	1287.8	879.1	64.8	R13	21	229.8	512.9	532.0	35.2	548.0	1387.9	770.3	64.8
R13	21	229.8	512.9	532.0	35.2	548.0	1387.9	770.3	64.8	R14	41	128.7	296.6	334.5	36.2	346.3	1165.9	598.1	61.1
R14	41	128.7	296.6	334.5	36.2	346.3	1165.9	598.1	61.1	R15	7	95.0	142.2	199.5	28.3	202.4	1369.9	366.3	61.1
R15	7	95.0	142.2	199.5	28.3	202.4	1369.9	366.3	61.1	R16	29	37.1	51.9	67.6	19.0	77.0	110.9	57.5	57.5
R16	29	37.1	51.9	67.6	19.0	77.0	110.9	57.5	57.5	R17	62	17.2	41.4	55.5	14.3	56.5	82.6	108.8	56.2
R17	62	17.2	41.4	55.5	14.3	56.5	82.6	108.8	56.2	R18	99	16.9	40.9	53.3	12.6	54.4	87.2	91.8	56.4
R18	99	16.9	40.9	53.3	12.6	54.4	87.2	91.8	56.4	R19	71	31.8	41.6	51.6	12.6	54.4	87.2	91.8	56.4
R19	71	31.8	41.6	51.6	12.6	54.4	87.2	91.8	56.4	R20	79	15.0	38.2	37.7	10.3	41.8	86.8	83.4	52.3
R20	79	15.0	38.2	37.7	10.3	41.8	86.8	83.4	52.3	R21	107	9.9	30.2	37.0	9.1	39.0	96.9	73.5	50.2
R21	107	9.9	30.2	37.0	9.1	39.0	96.9	73.5	50.2	R22	50	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
R22	50	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	R23	18	12.7	43.7	39.4	15.6	62.3	516.6	138.1	46.7
R23	18	12.7	43.7	39.4	15.6	62.3	516.6	138.1	46.7	R24	11	7.9	34.8	73.3	15.5	77.0	165.6	193.2	44.0
R24	11	7.9	34.8	73.3	15.5	77.0	165.6	193.2	44.0	T15									
R12	22	225.0	--	598.5	--	601.5	1181.0	975.3	68.5	R13	22	225.0	--	598.5	--	601.5	1181.0	975.3	68.5
R13	22	225.0	--	598.5	--	601.5	1181.0	975.3	68.5	R14	22	225.0	--	598.5	--	601.5	1181.0	975.3	68.5
R14	22	225.0	--	598.5	--	601.5	1181.0	975.3	68.5	R15	21	99.5	128.5	209.9	40.0	221.9	1500.6	399.3	59.9
R15	21	99.5	128.5	209.9	40.0	221.9	1500.6	399.3	59.9	R16	11	68.6	81.1	96.6	13.0	81.0	253.0	10.7	57.5
R16	11	68.6	81.1	96.6	13.0	81.0	253.0	10.7	57.5	R17	88	43.0	64.3	65.5	22.4	87.9	1511.5	139.4	64.6
R17	88	43.0	64.3	65.5	22.4	87.9	1511.5	139.4	64.6	R18	31	31.1	39.9	47.2	16.6	59.7	1282.5	116.9	57.5
R18	31	31.1	39.9	47.2	16.6	59.7	1282.5	116.9	57.5	R19	113	15.0	39.5	47.2	16.6	59.7	1282.5	116.9	57.5
R19	113	15.0	39.5	47.2	16.6	59.7	1282.5	116.9	57.5	R20	130	12.0	35.5	47.2	16.6	59.7	1282.5	116.9	57.5
R20	130	12.0	35.5	47.2	16.6	59.7	1282.5	116.9	57.5	R21	74	10.3	28.3	39.3	11.2	42.5	99.5	56.2	48.7
R21	74	10.3	28.3	39.3	11.2	42.5	99.5	56.2	48.7	R22	33	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7
R22	33	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7	R23	44	16.6	51.4	62.7	11.2	73.1	516.3	151.9	50.2
R23	44	16.6	51.4	62.7	11.2	73.1	516.3	151.9	50.2	R24	61	13.5	38.1	73.3	15.9	77.0	251.2	235.1	49.5
R24	61	13.5	38.1	73.3	15.9	77.0	251.2	235.1	49.5	R25	6	11.3	44.2	129.8	15.6	434.6	147.7	397.6	30.5
R25	6	11.3	44.2	129.8	15.6	434.6	147.7	397.6	30.5	T16									
R12	21	175.5	446.4	499.1	16.2	501.5	1234.7	873.3	63.8	R13	21	175.5	446.4	499.1	16.2	501.5	1234.7	873.3	63.8
R13	21	175.5	446.4	499.1	16.2	501.5	1234.7	873.3	63.8	R14	21	175.5	446.4	499.1	16.2	501.5	1234.7	873.3	63.8
R14	21	175.5	446.4	499.1	16.2	501.5	1234.7	873.3	63.8	R15	11	106.8	104.8	221.3	31.0	228.9	1644.5	351.3	61.7
R15	11	106.8	104.8	221.3	31.0	228.9	1644.5	351.3	61.7	R16	20	137.0	139.9	237.0	40.6	288.6	1831.6	481.6	61.7
R16	20	137.0	139.9	237.0	40.6	288.6	1831.6	481.6	61.7	R17	27	41.3	65.9	69.6	18.6	86.0	1197.4	161.3	59.7
R17	27	41.3	65.9	69.6	18.6	86.0	1197.4	161.3	59.7	R18	92	16.0	47.2	68.8	17.2	66.6	67.3	125.2	55.5
R18	92	16.0	47.2	68.8	17.2	66.6	67.3	125.2	55.5	R19	104	8.3	39.1	46.6	13.0	59.7	881.6	251.2	61.0
R19	104	8.3	39.1	46.6	13.0	59.7	881.6	251.2	61.0	R20	91	14.9	33.8	42.2	13.4	49.7	720.3	106.5	51.5
R20	91	14.9	33.8	42.2	13.4	49.7	720.3	106.5	51.5	R21	65	11.4	30.4	37.1	10.3	47.8	92.9	71.9	51.5
R21	65	11.4	30.4	37.1	10.3	47.8	92.9	71.9	51.5	R22	51	10.1	30.3	42.1	11.8	44.6	95.3	70.8	51.5
R22	51	10.1	30.3	42.1	11.8	44.6	95.3	70.8	51.5	R23	23	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7
R23	23	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7	R24	50	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
R24	50	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	R25	10	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7
R25	10	11.7	32.6	42.7	11.7	42.7	99.5	56.2	48.7	T17									
R12	20	250.0	379.5	600.0	221.3	604.7	1305.3	1000.9											

Table 1 continued.

Township	Number of tests	Plate of tests	Power	Static depth	Pump depth	Draw-down	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Township	Number of tests	Plate of tests	Power	Static depth	Pump depth	Draw-down	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency
T19	1	2	1	2	1	2	1	2	1	2	T20	1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
T21	1	2	1	2	1	2	1	2	1	2	T22	1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
T23	1	2	1	2	1	2	1	2	1	2	T24	1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
T25	1	2	1	2	1	2	1	2	1	2	T26	1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2
	1	2	1	2	1	2	1	2	1	2		1	2	1	2	1	2	1	2	1	2

Source: Courtesy of U. S. Geological Survey, Pacific Gas and Electric Company, and Southern California Edison Company; calculations by the authors.

We also grouped townships with similar pumping plant characteristics into 21 hydrographic areas. Mean values for these characteristics by areas appear in Table 2, and hydrographic area locations and boundaries in Figure 2.

Topography and ground water conditions (specific yield) greatly affect the motor horsepower, pump lift, and discharge for pumps in the San Joaquin Valley. The greatest mean pump discharge (g.p.m.) occurs in hydrographic area 4, which area includes the Valley trough area in Merced County. This hydrographic area lies on both sides of the San Joaquin River, and enjoys one of the best ground water supplies in California. Lowest electrical energy requirements per acre foot of water pumped (95.4 kilowatt-hours), is indicated for hydrographic area number 1, immediately north of area 4. This area includes that part of Stanislaus County extending from the San Joaquin River to the foothills of the Sierra Nevada mountains.

The highest horsepower pump motors occur in area 13, including the western portion of Fresno County around the Five Points area. Highest electrical energy requirements per acre-foot (747 kilowatt-hours), however, are in area 21 near Ford City, western Kern County. The number of pump tests (2) in this latter area was very small, however, and the data, therefore, are not statistically reliable as a sample of the entire area.

TABLE 2

Mean Pumping Plant Characteristics by Hydrographic Area,
San Joaquin Valley, 1949-54

Area number	Plate horse- power	Static depth	Pumping depth	Draw- down	Total lift	G.P.M.	K.W.H. per acre foot	Over-all plant efficiency	Number of tests
	1	2	3	4	5	6	7	8	9
1	24.6	30.4	48.6	18.7	50.5	1211.1	95.4	53.4	213
2	68.1	49.1	129.8	26.6	132.7	1298.9	256.8	54.6	83
3	65.0	89.2	141.1	28.2	144.0	1291.2	247.7	58.2	166
4	30.9	28.8	57.6	27.8	59.3	1469.9	110.0	56.2	191
5	20.0	37.1	64.7	26.4	66.3	772.5	136.0	53.5	85
6	22.6	63.0	80.0	17.0	81.7	771.0	155.0	54.8	386
7	19.9	55.5	69.9	14.6	72.1	754.4	140.8	54.0	1,233
8	147.4	290.3	364.1	38.5	371.6	1288.4	606.5	61.3	205
9	10.4	29.0	43.0	14.1	46.2	563.2	102.9	49.0	184
10	40.0	65.2	90.4	20.5	92.5	1246.6	159.0	60.3	391
11	14.4	35.6	49.0	13.3	52.6	693.4	103.7	52.6	1,420
12	11.4	58.0	73.8	16.1	79.0	365.6	194.0	45.6	514
13	173.7	344.8	426.6	38.0	429.6	1237.4	728.2	61.0	262
14	67.3	124.2	170.9	27.5	173.8	1020.7	318.1	55.7	275
15	22.5	83.8	101.1	17.4	104.5	551.9	220.6	49.8	2,591
16	16.0	157.3	177.0	20.1	179.5	249.9	423.8	47.0	727
17	63.0	203.3	225.0	22.0	230.3	763.8	442.6	54.7	1,192
18	40.1	179.5	237.5	36.8	241.1	452.2	501.5	50.8	34
19	41.2	81.8	99.9	17.7	104.4	1095.0	198.1	54.7	511
20	87.5	255.0	324.6	69.6	327.7	610.5	747.1	45.5	2
21	129.2	262.6	288.6	26.8	295.5	1334.5	507.8	59.9	337

Sources: Courtesy of U. S. Geological Survey, Pacific Gas and Electric Company, and Southern California Edison Company; calculations by the authors.

These same hydrographic areas provide the basis for sorting the 11,000 pump tests according to total lift. We used class intervals of 25 feet for this grouping within the range from 0 to 199.9 feet and 50 feet for the range from 200 to 500 feet (see Table 3).

Total pump lifts are lowest in the northeastern part of the San Joaquin Valley, and tend to increase from north to south and from east to west. For the entire Valley, well distribution by total lift was uneven and concentrated around two levels. Heaviest concentration centered around a lift of 63 feet, with a secondary concentration at the 226 foot level and the median lift at 91.7 feet. Thus, there were as many wells with lifts greater than 91.7 feet as there were with less than this lift.

The extremely high lifts on the Westside and in the Wheeler Ridge area heavily weigh the average lift for the entire Valley towards the upper end of the scale; the standard deviation about the 113 foot mean was 102.7 feet.

Over-all pumping plant efficiency averaged 52 percent for the entire 11,000 well sample. It was highest, 62 percent, in the two subareas with the maximum lift and horsepower. This high lift-high efficiency relationship reflects two causal factors: first, slightly higher efficiencies are built into the larger pumps; second, farmers watch operating efficiency and undertake to improve it when it drops, because they know that a slight decrease in efficiency sharply increases costs when pumping from extreme depths.

TABLE 3
Mean Pumping Plant Characteristics by Hydrographic Area and Total Lift, San Joaquin Valley, 1949-54

Area	Class interval in feet	Total lift	Pump depth	Plate horse-power	G.P.M.	K.W.H. per acre-foot	Overall plant efficiency	Number of tanks	Area	Class interval in feet	Total lift	Pump depth	Plate horse-power	G.P.M.	K.W.H. per acre-foot	Overall plant efficiency	Number of tanks
1	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
2	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
3	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
4	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
5	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
6	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
7	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1	36.8	20.6	1237.7	79.0	10.1	108	25-49.9	39.0	36.5	11.5	686.6	88.8	46.6	69	6
	50-74.9	57.4	38.8	1139.5	107.9	56.0	67	75-99.9	63.1	59.3	12.6	397.4	159.3	44.5	120	141	
	75-99.9	59.2	38.8	1139.5	107.9	56.0	67	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	120	
	100-124.9	107.2	106.3	13.1	254.1	236.6	48.4	95	125-149.9	137.7	127.1	11.7	166.8	390.8	41.1	17	17
	125-149.9	127.3	125.4	100.0	1990.0	210.0	68.0	1	150-174.9	163.1	139.9	26.0	109.4	576.3	51.0	26	26
	25-49.9	36.0	31.9	38.8	843.2	179.8	33.8	6	175-199.9	186.9	192.0	12.0	240.0	394.7	51.2	4	4
	50-74.9	64.8	66.7	35.0	1169.0	120.7	57.5	17	200-249.9	211.9	128.8	35.0	93.7	386.1	57.0	3	3
	75-99.9	87.0	101.1	109.2	60.0	1356.2	28.4	10	250-299.9	289.9	107.0	130.0	137.0	100.8	60.0	1	1
	100-124.9	101.1	109.2	60.0	1356.2	28.4	10	300-349.9	349.9	107.0	130.0	137.0	100.8	60.0	1	1	
8	0-24.9	21.6	18.8	11.8	974.3	62.1	38.4	12	0-24.9	17.6	28.8	6.5	299.5	110.8	27.1	6	9
	25-49.9	39.1															

An important question to farmers and agencies serving them is, "How do pumping plant characteristics vary in relation to changes in motor horsepower"? In order to answer this question, we grouped these 11,000 pump tests by nameplate horsepower, and retabulated them.

The tabulation includes six possible groups, according to horsepower, for each hydrographic area: 0-4.9, 5-14.9, 15-49.9, 50-99.9, 100-249.9, and equal to, or greater than 250 horsepower. We note here that a case can be made for using input rather than plate horsepower in such tabulations, because the former indicates actual power input. Motors can vary in actual load within certain limits (see Table 4).

TABLE 4

Mean Pumping Plant Characteristics by Hydrographic Area and Plate Horsepower San Joaquin Valley, 1949-54

Area	Class interval in H.P.	Horse-power	Pump depth	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Number of tests	Area	Class interval in H.P.	Horse-power	Pump depth	Total lift	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Number of tests
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
1	0- 4.9	2.0	15.1	15.1	120.0	139.0	11.0	1	12	0- 4.9	2.9	60.6	64.5	99.5	312.2	29.6	10
	5- 14.9	9.2	37.0	39.8	98.8	86.8	47.7	30		5- 14.9	8.1	73.3	78.0	256.4	197.1	44.6	351
	15- 49.9	22.8	47.2	48.9	121.7	92.0	53.7	161		15- 49.9	18.2	82.4	82.4	635.5	179.5	48.9	152
	50- 99.9	57.4	72.9	75.1	212.5	125.9	60.5	19		100-249.9	220.0	62.1	66.5	337.0	119.0	57.0	1
	100-249.9	100.0	116.8	118.2	2245.0	190.0	63.5	2									
2	0- 4.9	3.0	23.8	29.2	47.0	39.0	9.5	2	13	15- 49.9	35.0	204.8	207.8	449.5	200.2	57.0	2
	5- 14.9	9.2	32.4	34.2	243.0	99.0	54.0	1		50- 99.9	61.7	242.1	244.8	759.0	449.9	57.7	27
	15- 49.9	34.3	77.8	80.0	1234.3	154.6	55.2	29		100-249.9	152.9	401.9	404.8	1191.5	660.6	60.8	165
	50- 99.9	68.1	140.5	142.7	1288.1	265.7	57.7	27		> 250.0	272.8	566.4	569.8	1561.9	922.1	62.7	68
	100-249.9	117.1	192.6	197.0	1537.3	368.8	54.2	24									
3	5- 14.9	9.6	37.1	38.3	897.6	114.5	44.4	5	14	5- 14.9	8.7	90.7	92.4	259.4	250.0	42.8	13
	15- 49.9	28.2	72.4	74.8	1167.3	139.5	56.4	84		15- 49.9	29.2	127.2	130.2	622.7	257.1	53.3	101
	50- 99.9	59.4	155.1	158.6	1178.0	276.8	58.0	32		50- 99.9	63.2	175.5	179.0	1055.8	316.0	57.4	94
	100-249.9	133.8	245.1	248.9	1670.3	398.4	63.4	41		100-249.9	141.8	245.9	248.3	1719.2	416.6	59.4	67
	> 250.0	250.0	534.7	536.8	1407.0	907.6	61.2	4									
4	5- 14.9	8.9	35.3	38.5	554.9	81.4	49.4	11	15	0- 4.9	2.8	72.7	75.8	77.8	288.2	29.9	22
	15- 49.9	27.2	53.6	55.3	1417.1	104.7	55.9	147		5- 14.9	8.3	77.9	81.2	270.4	198.9	44.1	760
	50- 99.9	54.7	82.6	84.1	2009.9	143.5	60.0	33		15- 49.9	23.9	39.6	43.2	612.6	218.4	51.5	1,561
										50- 99.9	56.3	157.7	160.8	1019.3	296.3	57.9	234
										100-249.9	105.4	162.2	164.9	1991.5	269.7	63.1	14
5	5- 14.9	9.0	51.5	53.7	395.1	133.8	46.5	22	16	0- 4.9	3.0	41.1	46.9	49.0	326.7	15.0	1
	15- 49.9	20.5	67.7	69.2	805.2	136.6	55.1	57		5- 14.9	8.7	162.0	162.9	151.8	406.8	46.5	261
	50- 99.9	55.0	84.2	85.9	1845.5	138.1	64.3	6		15- 49.9	19.8	185.7	189.1	300.0	434.7	47.2	459
										50- 99.9	50.0	182.5	188.8	715.0	339.4	57.3	6
6	5- 14.9	9.3	74.6	76.2	273.6	181.4	44.5	34	17	5- 14.9	10.4	122.3	129.6	264.0	316.8	47.6	24
	15- 49.9	21.9	80.0	81.8	771.0	152.2	55.6	334		15- 49.9	28.1	168.8	173.2	463.8	354.2	52.4	485
	50- 99.9	60.3	90.4	92.0	1708.6	157.7	59.0	18		50- 99.9	63.6	236.1	240.6	837.0	454.2	56.3	389
										100-249.9	122.0	310.5	318.7	1183.9	584.0	56.9	290
										> 250.0	290.0	344.8	348.3	2556.8	550.4	65.0	4
7	0- 4.9	2.8	57.7	61.8	58.6	323.4	25.6	5	18	5- 14.9	10.0	194.5	199.0	131.3	487.5	50.7	3
	5- 14.9	8.8	56.8	58.8	386.9	131.0	48.2	270		15- 49.9	25.0	225.7	229.3	261.1	499.6	48.0	22
	15- 49.9	21.3	73.3	75.0	813.8	142.0	55.6	960		50- 99.9	64.2	247.9	250.7	970.2	460.7	57.3	6
	50- 99.9	60.3	82.2	91.5	1282.2	150.8	61.7	34		100-249.9	133.3	346.7	350.1	1138.0	611.0	59.3	3
	100-249.9	137.5	91.0	117.3	3646.0	209.9	57.2	4									
8	5- 14.9	31.7	169.6	172.5	1305.7	293.2	60.0	3	19	5- 14.9	9.1	70.2	75.0	339.0	179.1	46.1	47
	50- 99.9	66.1	175.1	181.3	1339.9	331.9	57.5	31		15- 49.9	25.8	81.9	85.7	873.0	170.4	52.9	284
	100-249.9	146.8	381.6	390.3	1213.0	637.0	61.6	147		50- 99.9	64.3	129.2	134.3	1948.2	233.4	59.9	140
										100-249.9	107.5	160.4	167.6	1972.8	292.8	59.0	40
	> 250.0	270.8	525.2	528.1	1682.0	813.5	64.8	24									
9	0- 4.9	3.0	39.9	43.7	109.5	151.0	51.7	6	20	50- 99.9	75.0	297.0	302.0	484.0	781.8	40.0	1
	5- 14.9	8.0	42.8	46.4	411.5	106.6	47.6	119		100-249.9	100.0	352.2	353.4	737.0	712.4	51.0	1
	15- 49.9	15.8	43.7	46.1	915.2	90.5	53.6	59									
10	5- 14.9	8.7	52.3	57.2	434.7	102.8	51.1	27	21	5- 14.9	9.0	129.5	179.0	133.0	305.4	55.5	2
	15- 49.9	26.4	70.3	71.8	1089.4	125.3	59.6	235		15- 49.9	26.3	170.3	174.8	459.2	415.2	48.5	30
	50- 99.9	61.5	115.1	117.8	1671.9	200.8	63.4	104		50- 99.9	65.7	236.0	240.8	919.1	404.8	60.3	40
	100-249.9	112.0	216.8	219.8	1831.5	363.0	64.2	25		100-249.9	148.6	305.9	313.3	1499.8	529.0	61.0	249
										> 250.0	254.5	463.5	467.6	1896.6	737.2	65.3	11
11	0- 4.9	3.0	27.1	29.9	180.3	86.8	35.3	3									
	5- 14.9	8.8	43.2	46.6	476.8	96.5	49.9	758									
	15- 49.9	18.4	53.6	56.9	922.0	105.9	55.7	640									
	50- 99.9	67.5	68.7	104.1	1033.9	171.0	56.8	10									
	100-249.9	152.8	192.4	194.5	2465.6	322.4	60.9	9									

Irrigation Wells

The California State Water Code, Sections 7076, 7077, and 7078 requires anyone who drills a new well, deepens an existing one, or reconditions or abandons a water well, to report the work accomplished to the appropriate Regional Water Pollution Control Board. These reports include information on location, proposed use, equipment used, casing installed (including diameter, gauge and depth), extent of gravel pack, perforations in casing wall, water levels, results of pump tests, and a log of the formations and material encountered in drilling. This law has only been in effect since 1949; compliance, furthermore, has been far from complete. Thus, the number of reports available is small, relative to numbers of wells in operation.

We obtained 584 usable reports from Regional Water Pollution Control Board Number 5, which includes the San Joaquin Valley. Not only was this sample small in size, but individual reports were incomplete in certain categories of information.

These 584 reports, however, represent the best information available on the subject; in spite of their admitted limitations they proved to be very helpful.

We present in Table 5 mean values for well characteristics for each hydrographic area for which data were available, as calculated from these reports.

Pump Operating Characteristics

Many bulletins, circulars, and pamphlets are available on selecting, operating and using irrigation pumps. This section includes a limited selection of such information to illustrate how changes in certain operating characteristics can affect the cost of pumping water.

Farmers in the San Joaquin Valley operate a wide range of pumps and motors to meet the varying conditions under which they pump irrigation water. A farmer's first step in selecting a pump is to examine pump performance curves available from pump manufacturers (see Figure 3). The pump in Figure 3 attains its maximum

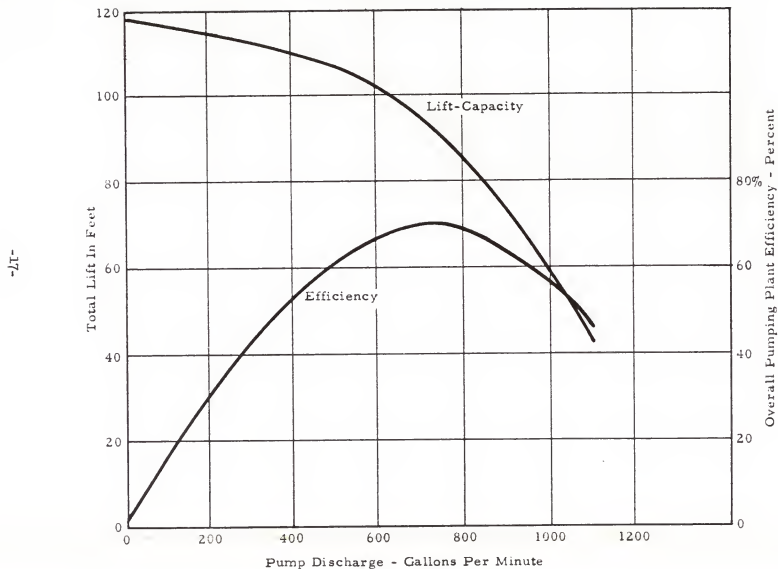
TABLE 5
Mean Irrigation Well Characteristics by Hydrographic Area, San Joaquin Valley, 1950-60

Area number	Total number of reports	Type of rig		Type casing		Casing thickness		Casing diameter		Casing depth		Gravel packed bore		Gravel packed depth		Casing perforations		Total well development	
		Rotary	Cable	Single casing	Double casing	Number reporting	Thickness (in.)	Number reporting	Top diameter (in.)	Number reporting	Depth (ft.)	Number reporting	Diameter (in.)	Number reporting	Depth (ft.)	Number reporting	Depth perforation (ft.)	Number reporting	Depth (ft.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
3	7	3	4	7	0	7	.214	7	18	7	171	7	30	2	1,116	7	154	6	502
7	41	6	35	41	0	40	.140	41	13	41	188	6	22	6	253	23	112	37	228
8	3	3	0	3	0	3	.312	3	16	3	722	0	0	0	0	3	342	3	1,016
10	47	19	27	40	7	41	.153	46	14	47	250	21	23	23	262	33	148	47	262
11	193	74	119	187	5	188	.119	191	12	193	154	34	21	32	184	88	112	193	184
12	29	2	27	28	0	28	.110	28	12	28	126	0	0	0	0	17	71	29	155
13	6	6	0	6	0	6	.236	6	14	6	624	5	25	4	959	5	548	6	1,044
14	28	22	6	27	0	28	.219	28	15	28	614	20	25	8	577	20	324	26	678
15	68	26	41	66	0	66	.158	66	13	66	408	15	31	7	666	30	196	65	410
17	44	36	8	44	0	44	.234	43	14	44	1,000	32	24	23	1,172	35	529	44	1,019
19	94	69	25	91	0	92	.225	93	15	93	453	67	25	46	513	92	277	89	476
20	6	6	0	6	0	6	.270	6	15	6	821	4	28	1	1,476	4	625	4	1,250
21	18	13	5	17	0	18	.235	18	19	18	805	10	26	9	888	17	495	17	842

Source: California Regional Water Control Board Number 5; calculations by the authors.

Figure 3

Pumping Plant Performance For Typical Deep Well
Turbine Pump



Source: Pump manufacturer's data.

discharge (g.p.m.) at a total lift (lift-capacity) of about 40 feet; maximum plant efficiency accompanies a discharge of about 700 g.p.m. If a farmer selects a pump for a well with an initial total lift of 50 feet, only to find a falling water table, two things will happen; first, pump discharge will decrease; second, plant efficiency will increase until the discharge falls below 700 g.p.m., then it also will decrease. It happens quite frequently that water tables fall in the southern San Joaquin Valley. Such occurrences may be due to seasonal draw-down or to an overdraft of the ground water basin. Regardless of cause, a drop in water table, such as in the example cited, may mean increased costs for the operator. According to the formula for computing kilowatt-hours per acre foot of water, this effect will depend on the relative slopes of the two curves for head-capacity and efficiency ($KWH/acre-foot = 1.024 \cdot \frac{\text{total lift}}{\text{plant efficiency}}$). The power bill may increase, decrease, or remain constant when the water table falls. Sharp declines usually will bring higher pumping costs, and may mean that the plant will be unable to furnish enough water for irrigating the crops that it is supposed to serve. Such declines can be serious enough that the well ceases to produce any appreciable quantity of water, and therefore, the farmer must deepen it, and change horsepower and other plant characteristics, or make other arrangements to obtain the water necessary for his operation.

Seasonal Drawdown in Wells

In almost all parts of the San Joaquin Valley pumping lifts are smallest early in the year immediately after winter rains and the melting snow packs have recharged the aquifers. Total lifts then increase as pumping continues during the summer irrigation season and reach their maxima in the late summer and fall. Well hydrographs for various locations in the Valley, obtained from the U. S. Bureau of Reclamation, show this typical pattern (see Figure 4).

Rainfall is light in Westside, and stream runoffs supply only small amounts of recharge. Quantities pumped here are greater than annual recharge. The

FIGURE 4

A. TYPICAL WELL HYDROGRAPHS NORTHERN & EASTERN SAN JOAQUIN VALLEY

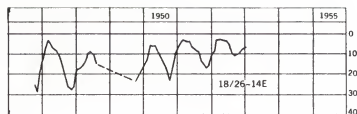
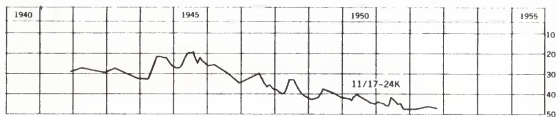
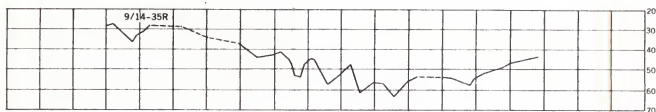
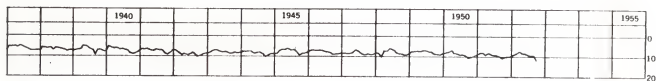


FIGURE 4

B. TYPICAL WELL HYDROGRAPH SAN JOAQUIN VALLEY EASTSIDE

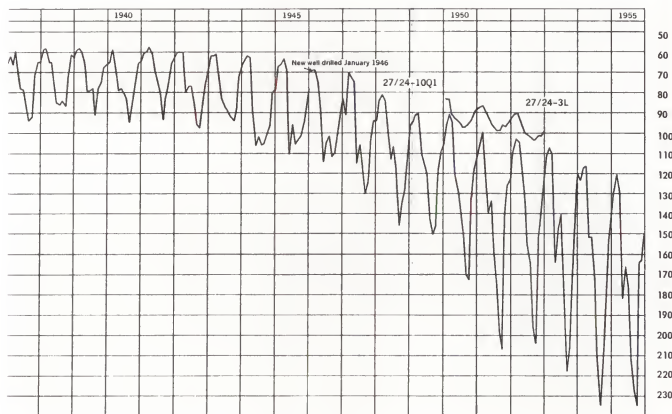
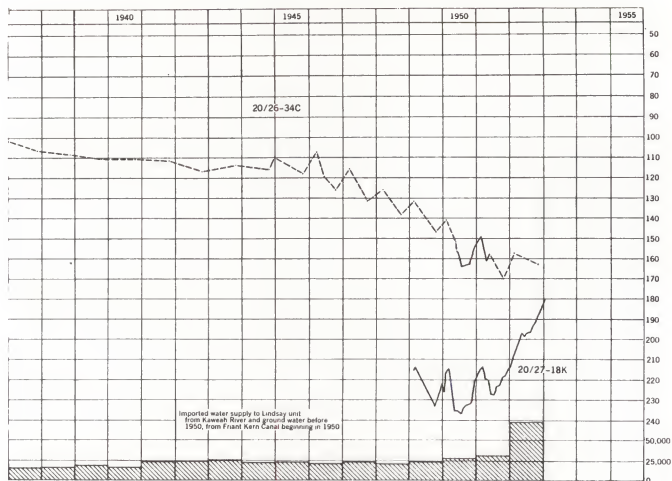


FIGURE 4

C. TYPICAL WELL HYDROGRAPHS SAN JOAQUIN VALLEY WESTSIDE

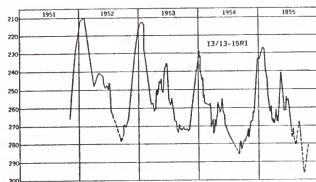
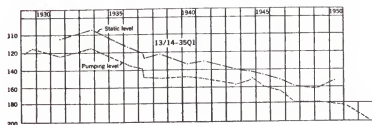
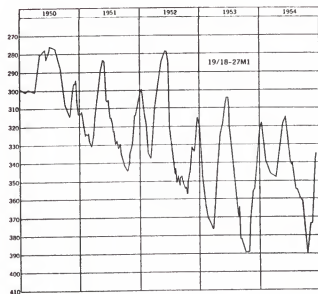
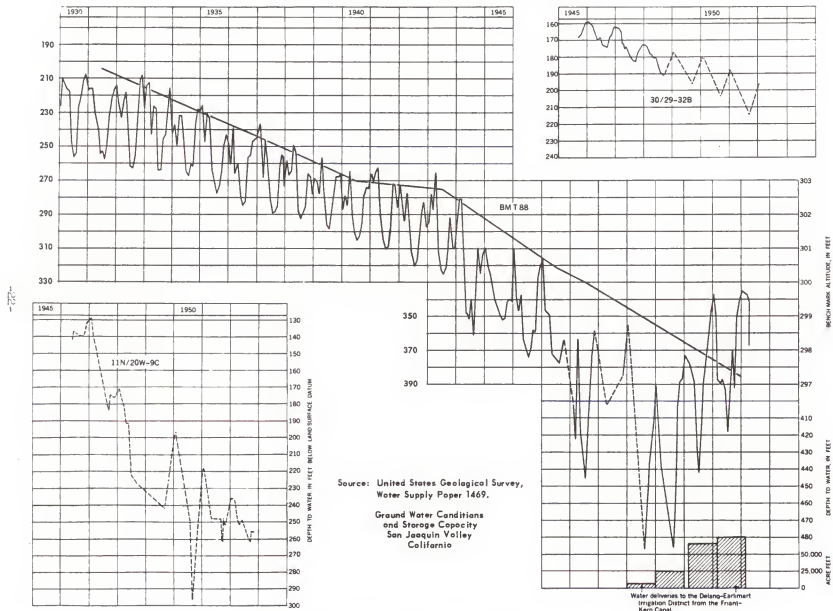


FIGURE 4

D. TYPICAL WELL HYDROGRAPHS SOUTHERN SAN JOAQUIN VALLEY



resulting ground water overdraft causes average total lift to increase year after year, and forces farmers periodically to deepen wells, increase motor horsepower, and increase the number of pump stages. All of these capital improvements are expensive (see Figure 4-c).

Typical Power Costs for Pumping Irrigation Water

It is useful in this analysis to compute typical power costs for pumping irrigation water in the several hydrographic areas of the San Joaquin Valley. Total pumping lift is the most important physical factor governing kilowatt-hours and power costs per acre-foot of water. We selected values for mean pump characteristics in modal class intervals (those with the greatest number of tests) to represent a typical pumping plant in each of the 21 hydrographic areas (see Table 3). Our first assumption in using these data is that these physical characteristics (total lift, discharge, and efficiency) represent midseason conditions with respect to seasonal drawdown. We then estimated total energy cost by calculating kilowatt-hours and outlays for one-fourth of the water under spring, one-half under midseason, and one-fourth under late summer and fall conditions. Some of the hydrographic areas with very similar pumping characteristics are combined in these calculations.

Assumed total lifts, discharges in g.p.m. and plant efficiencies for these three pumping periods appear in Table 6. We estimated these seasonal values for the three pumping periods by fitting pump performance curves to the typical pump characteristics for each area. Pump dealers and manufacturers' representatives furnished valuable counsel and aid in preparing these estimates, which then served us as the basis for estimating costs of pump and motor components. We recognize that our estimates have obvious limitations, based on the kinds of data available and the methods that were applicable in preparing them. We suggest, in spite of these faults, that these estimates according to hydrographic areas are useful.

TABLE 6

Assumed Pump Characteristics for Three Pumping Periods by
Hydrographic Area, San Joaquin Valley

Area	High lift period			Medium lift period			Low lift period		
	Total lift	G.P.M.	Plant eff.	Total lift	G.P.M.	Plant eff.	Total lift	G.P.M.	Plant eff.
	1 (ft.)	2	3 (%)	4 (ft.)	5	6 (%)	7 (ft.)	8	9 (%)
1 & 4	44.8	1,194	50.4	39.8	1,344	52.4	34.8	1,495	54.4
9 & 11	45.9	404	46.0	40.9	654	50.0	35.9	904	54.0
10	65.8	975	56.0	60.8	1,074	58.0	55.8	1,175	60.0
19	72.7	884	48.9	62.7	1,085	52.9	52.7	1,285	56.9
2 & 3	67.3	1,336	56.5	62.3	1,487	60.5	57.3	1,637	64.5
7	64.2	730	52.6	62.2	769	53.6	60.2	810	54.6
5	64.3	718	53.6	62.3	758	54.6	60.3	978	55.6
6	89.1	614	51.2	87.1	654	55.2	85.1	694	59.2
12	87.2	246	44.8	87.2	246	44.8	87.2	246	44.8
15	93.1	382	45.7	88.1	482	48.7	83.1	582	51.7
17	147.3	528	48.6	137.3	639	53.6	127.3	749	58.6
14	144.3	863	52.7	139.3	918	54.7	134.3	983	56.7
16	167.6	181	44.6	162.6	241	46.6	157.6	301	48.6
18	--	--	--	--	--	--	--	--	--
20 & 21	340.9	1,127	50.0	325.9	1,427	62.0	310.9	1,727	74.0
8 & 13	439.3	921	49.9	424.3	1,221	61.9	409.3	1,521	73.9

Source: Calculated by the authors from pumping plant and well characteristics and engineering data.

In the absence of more precise information, they provide an over-all perspective on the factors affecting power costs for pumping irrigation water in the San Joaquin Valley. They also indicate some of the major variations among these hydrographic areas.

Repair and Maintenance Costs

Neither accurate records nor comprehensive sample data on pump repair and maintenance costs for the San Joaquin Valley were available for this analysis. One of the larger farming companies in the Valley, however, did furnish detailed records on repair and maintenance costs for a five-year period including more than 400 pumps. These pumps, scattered over a wide geographic area, represent three distinct ground water conditions. Total pump lifts under condition Number 1 are less than 100 feet, while the water table is fairly stable and subject to little or no ground water overdraft. Condition Number 2 represents conditions with total pump lift about 160 feet, and the water table falling at a rate of 3-4 feet per year. Condition Number 3 has the most extreme conditions; total lift is about 350 feet and the water table is falling at a rate of 8-10 feet per year.

The repair costs presented here also have their limitations. Again, however, we believe that they are sufficiently representative to justify using them in preparing estimates for other parts of the Valley. We obtained such estimates by expressing repairs and maintenance costs as percentage of original outlays for the pumps and motors in the several hydrographic areas (see Table 7).

Well Drilling Costs

Well drilling charges, and the methods used to determine them vary widely among areas. The most important cost-regulating factors include well depth, type of material drilled through, casing diameter and thickness, and amount of gravel packing.

A survey of well drillers in the San Joaquin Valley revealed a wide range in charges among the various areas (see Table 8).

TABLE 7

Irrigation Pump and Well Repairs and Maintenance Costs for
Three Ground Water Conditions, San Joaquin Valley

Item	Area No. 1		Area No. 2		Area No. 3	
	Cost	Percent of total	Cost	Percent of total	Cost	Percent of total
	1	2	3	4	5	6
<u>Repairs:</u>						
Motor	22.72	14.7	57.60	12.8	a/	
Electrical	6.56	4.3	23.68	5.2		
Column, tube, and shaft	.48	.3	17.28	3.8		
Well	9.60	6.2	7.36	1.6		
Pump head	1.12	.7	15.84	3.5		
Unclassified	2.72	1.8	6.40	1.4		
Subtotal	43.20	28.0	128.16	28.4	402.08	28.0
<u>Costs incurred due to increased pump lift:</u>						
Pump bowl changes	44.80	29.0	115.36	25.5		
Horsepower increases	56.16	36.4	201.76	44.7		
Other capital increases	10.08	6.5	6.40	1.4		
Subtotal	111.04	72.0	323.52	71.6	1,033.92	72.0
TOTAL	154.24	100.0	451.68	100.0	1,436.00	100.0

a/ Costs not broken down.

Source: Calculated by the authors from pumping plant characteristics and engineering data.

TABLE 8

Typical Well Drilling Charges per Foot of Depth in the
San Joaquin Valley,^{a/} (taxes not included)

Casing size		Drilling		Perforating the casing
Top diameter (inches)	Thick- ness	Without gravel envelope	With gravel envelope	
	1	2	3	4
	gauge	dollars		
12	10	5.25	6.75	1.66
14	10	6.25	8.75	1.94
14	8	7.40	10.00	2.44
16	10	7.25	10.75	2.21
16	8	8.40	12.00	2.79
18	8	9.40	14.00	3.13

^{a/} Well development by pumping; average of \$200 - \$350 for shallow wells, \$1,000 for wells exceeding 1,000 feet in depth.

Source: Data obtained by interviews with well drillers.

Average Total Pumping Costs

Annual fixed costs are those that do not vary with the amounts of water pumped. In this analysis, fixed costs include two noncash and three cash items: depreciation, interest on investment, capital improvements, taxes, and demand charges. Annual depreciation is the yearly cost for consuming the capital investment. We obtained this item by dividing original cost, less any salvage value, by the estimated life for the pump or well in years. The assumption in this study is that 40 percent of the original motor cost represents the salvage value for the entire pumping plant.

Pump dealers, farmers, and others with knowledge of conditions in the areas, furnished information on length of life for the wells and pumps. These are difficult values to estimate for many of the areas, especially for the Westside and the southern tip of the Valley. Very few wells in these areas have existed for as long a period of time as that estimated to be the average length of life. Interest on investment is a noncash cost for using the average capital invested in the facilities, calculated at six percent per annum in this study.

Capital improvement costs appearing in Table 7 include fixed costs, due to declining water tables. Among the specific requirements necessitating such added capital are increased horsepower, additional stages for the pump, and longer columns, tubes, and shafts essential to maintain pump discharges at greater pumping depths. We list these under fixed costs because an individual pump can exert little or no affect upon the ground water levels in large basins such as those in the San Joaquin Valley. Operators, however, must make the expenditures involved in order to use the plants. Taxes represent a cash overhead cost, levied by county and local authorities on the assessed value of property.

The service or demand charge for the pump also is a cash outlay, charged by power companies. These are annual costs varying with motor horsepower, and not

according to hours of operation (see Appendix Table 1 for schedule). Power companies levy the demand charge if the motor is connected to their lines. It can be avoided only by disconnecting the unit. We have assumed that the farms in this study are going concerns, and therefore, that these charge represent fixed costs.

Variable expenses include all required outlays that vary with the quantity of water pumped. Easiest of these to determine is the pumping power or energy charge; it is based upon the number of kilowatt-hours used by the motor, and is determined by applying power company rates shown in the Appendix. Our estimates in this study reflect the three assumed seasonal pumping conditions. We obtained the total energy charge on the further assumption that a pump can serve one acre for each 9 g.p.m. of discharge at midseason, and that the full season's irrigation requires 36 inches of water per acre.

We distributed our estimated total annual repair and maintenance costs over the total quantities of water pumped during the season. The sums of these fixed and variable costs represent total estimated costs for pumping irrigation water in the various San Joaquin Valley hydrographic areas (see Table 9).

Surface Water Supplies

Most San Joaquin Valley operators on irrigated farms depend on surface water sources to supplement ground water supplies. These supplemental quantities become most critical during drought periods. Prolonged droughts, extending through two or more years, cause recharges of underground basin to be less than normal. These reductions, in turn, lead to pumping overdrafts and increased lifts. Surface supplies also are shortest during such periods, due to reduced stream runoffs.

It is practically impossible to generalize about surface irrigation water supplies in the San Joaquin Valley. This is due to the statutory and regulatory framework governing California water allocations, and to the number and types of organizations distributing water to farmers.

TABLE 9

Investment in Wells and Pumping Plants and Costs of Pumping Water by Hydrographic Area,
San Joaquin Valley

Area	Well cost	Est. well life	Pump cost	Est. pump life	Total annual depreciation ^a	Interest and tax	Cost due to lower water table ^b	Service demand charge	Total fixed cost	Repair and maintenance	Energy charge	Quantity pumped ^c	Fixed cost per ac. ft.	Variable cost per ac. ft.	Total cost per ac. ft.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	dollars	years	dollars	years			dollars					ac. ft.		dollars	
1 & 4	2,301	20	2,790	20	242.85	204.89	0	134.60	582.34	55.80	439.40	449.7	1.29	1.10	2.39
9 & 11	1,406	20	1,060	20	140.89	138.80	74.40	74.60	428.69	37.20	135.65	218.1	1.97	.79	2.76
10	2,600	20	2,598	20	217.55	220.92	103.92	168.25	710.64	51.96	495.50	358.2	1.98	1.53	3.51
19	7,044	15	2,598	20	583.15	409.78	103.92	168.25	1,265.10	51.96	547.82	361.5	3.50	1.66	5.16
2 & 3	6,122	20	3,545	20	483.38	495.85	0	201.90	1,181.13	70.90	625.02	495.6	2.38	1.40	3.78
7	2,002	20	2,580	20	197.38	194.74	0	134.60	526.72	51.60	393.48	265.5	1.98	1.68	3.66
5	2,002	20	2,580	20	197.38	194.74	0	134.60	526.72	51.60	394.66	252.6	2.09	1.73	3.82
12	2,002	20	2,387	20	212.73	207.78	0	134.60	555.11	57.74	437.38	217.8	2.55	2.27	4.82
16	1,177	20	2,160	20	146.73	141.82	0	174.60	463.15	43.20	130.25	82.2	5.63	2.11	7.74
15	2,836	20	2,391	20	246.29	243.40	0	134.60	624.29	57.82	387.51	160.5	3.89	2.77	6.66
17	12,980	20	4,422	20	721.55	737.58	309.54	201.90	1,970.57	132.66	686.32	213.0	9.25	3.84	13.09
14	9,766	15	4,769	20	864.22	617.74	333.83	299.50	2,115.29	143.07	962.14	306.0	6.91	3.61	10.52
16/ 18 ^d	2,836	20	3,179	20	260.69	255.64	0	134.60	650.93	95.37	377.84	80.4	8.10	5.89	13.99
20 & 21	---	15	16,206	20	1,731.77	---	---	---	---	---	---	---	---	---	---
8 & 13	14,000	15	17,700	15	2,013.33	1,347.25	1,134.42	789.00	4,981.74	486.18	3,016.78	475.8	10.47	7.36	17.83
							1,239.00	789.00	5,388.58	531.00	3,288.32	406.8	13.25	9.39	22.64

a/ Salvage value of 40 percent of pump cost was credited to pump unit.

b/ Four percent of new pump cost for areas 9 & 11, 10 & 19; 7 percent for areas 17, 14, 20 & 21, and 8 & 13.

c/ Thirty-six acre inches per acre of summer crops. This will understate the amount pumped in areas where winter crops are irrigated and will cause the cost per acre foot to be overstated for these same areas.

d/ Insufficient information.

Source: Calculated by authors from pumping plant and well characteristics and engineering data.

Riparian rights to stream flow are important to contiguous land holders, but only a small portion of Valley land is eligible for water under the Riparian doctrine. Appropriative rights are the most important basis for obtaining water in terms of land area, but the supply of water available to an individual grower under this doctrine depends upon circumstances affecting the specific case.

Either individuals or organizations may hold appropriative rights. Individuals, furthermore, may assign their rights to an organization, or retain them and arrange for an organization created for this purpose to deliver water to them. The rules governing appropriative rights specify the time, place, and quantities that the holder may divert. Regulations concerning time also specify the minimum flow that must be in the stream before the appropriative right holder may divert, and the times of the year he may divert this water.

Organizations distributing water may obtain their water supplies from more than one source. An irrigation district, for example, may divert water from a stream, have a contract with the Bureau of Reclamation to obtain water from an interriver basin aqueduct, and also pump from its own underground wells.

Irrigation water delivery can occur under one or more of several methods. The most obvious, and a very important method, is to conduct water through canals or pipelines to farm headgates. The second method, also important and widely used, is to use the water in recharging underground basins artificially. Several procedures are available for accomplishing such deliveries; spreading water through especially constructed beds or fields, pumping it down abandoned well shafts, or feeding it into unlined canals and ditches during the off-season for irrigation. In each instance, water percolates downward to accumulate in underground storage, later being pumped by individual farmers as they need it.

Wide year-to-year variations characterize irrigation water supplies available for distribution by many irrigation districts, and other agencies. A district with a senior appropriative right, for example, will have fairly reliable water supplies except during the driest years. Another district, or mutual water company, with a

junior appropriative right may receive water only during high precipitation years, or during high stream flow seasons. Farmers in certain parts of the San Joaquin Valley have filed claims for flood waters that cannot be expected more than once in 20 years.

Year-to-year fluctuations in irrigation water supplies can be reduced by conservation storage dams. Such structures enable the water agency to carry over to the following or later years the excess runoff in a wet year. Some irrigation districts have constructed their own storage dams; others have entered into agreements with governmental agencies for storage capacity behind multiple-purpose dams. Very little research has been done to determine optimum carry-over policies for irrigation water storage.

Runoff within any given year varies widely among streamas, although there is a tendency for streams in the same general region to vary in the same direction. Streams with large watersheds in the high mountain areas of the Sierra Nevadas have less variation in runoff, however, than those streams with watersheds in the foothills and low elevations (see Table 10 for major stream flows entering the San Joaquin Valley 1950-1960).

Actual farm headgate deliveries by irrigation districts do not always vary directly with stream runoff. Conservation storage, the nature of the rights held by the district, the possibility that water is imported from other watersheds by the Bureau of Reclamation, all may affect such deliveries. Those responsible for water spreading and other methods of recharge also may modify the influence of stream flows by curtailing recharge during dry years; instead, delivering the water directly to farms.

We have listed the sources of supply, and water supplied per irrigated acre for selected irrigation districts in the San Joaquin Valley for eight years (see Table 11).

TABLE 10

Seasonal Flow for Major Streams in the San Joaquin Valley as
Percent of Normal, 1950-51 to 1959-60

Stream	Year									
	1959- 1960	1958- 1959	1957- 1958	1956- 1957	1955- 1956	1954- 1955	1953- 1954	1952- 1953	1951- 1952	1950- 1951
	1	2	3	4	5	6	7	8	9	10
	percent									
San Joaquin	47	64	119	76	173	66	72	67	173	105
Kaweah	44	49	126	73	176	68	75	75	203	103
Tule	28	40	149	53	169	49	76	83	263	68
Kern	41	76	113	63	103	54	72	84	235	90
Kings	43	60	127	75	141	68	75	69	170	97
Stanislaus	51	49	107	65	162	59	77	83	165	146
Toulumne	57	54	115	65	178	61	78	83	165	134
Merced	49	46	122	52	172	54	68	63	160	124

Source: Water Conditions Report, California Department of Water Resources.

TABLE 11

Surface Irrigation Water Supply by Irrigation District, 1951-58

District	Source	1958				1957				1956				1955 a				1954				1953				1952				1951			
		Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre	Total deliv. (acre feet)	Irrigated acres	Acre feet per acre			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Alpaugh	Wells & C.V.P.	7,573	6,608	1.15	--	--	--	18,000	9,780	2.10	11,167	5,480	2.06	10,280	5,430	1.88	11,310	5,590	2.68	13,883	6,500	2.13	18,493	7,000	2.04	--	--	--	--	--	--		
Alta	Kings River & C.V.P.	189,045	97,397	1.90	159,361	83,990	1.89	207,000	97,190	2.13	189,000	97,190	2.06	189,000	97,190	2.06	189,000	97,190	2.06	189,000	97,190	2.06	189,000	97,190	2.06	189,000	97,190	2.06	189,000	97,190	2.06		
Banta-Carlson	San Joaquin River,	34,817	16,900	2.06	43,070	17,887	2.49	37,997	18,589	2.41	46,082	15,118	3.04	48,085	18,154	2.34	43,791	17,617	2.48	33,831	17,570	1.92	39,382	14,491	2.72	--	--	--	--	--	--		
Corcoran	Wells & C.V.P.	54,039	29,860	1.80	68,708	35,105	1.96	61,506	34,400	1.78	64,675	34,585	1.89	48,085	33,200	1.46	47,004	31,415	1.50	43,443	43,443	1.00	40,468	38,978	1.03	--	--	--	--	--	--		
Delano-Bartlett	Wells & C.V.P.	151,834	49,374	3.07	157,591	48,792	3.23	168,613	49,635	3.37	--	39,000	--	96,893	39,000	2.77	67,677	20,381	3.31	58,412	15,000	3.49	86,509	43,534	.61	--	--	--	--	--	--		
Delano-Bartlett	Wells & C.V.P.	22,558	11,805	1.91	19,470	16,539	1.55	19,503	11,794	1.66	--	--	--	34,105	11,975	2.85	33,710	11,834	2.85	33,504	11,796	2.84	38,302	11,806	2.74	6,280	11,000	--	--	--	--		
Fresno	Wells & C.V.P.	417,138	198,746	2.16	313,166	198,746	1.62	960,891	--	--	366,896	178,472	2.13	407,581	171,900	2.37	403,383	171,900	2.35	543,168	169,800	3.20	449,859	169,800	2.64	--	--	--	--	--	--		
James	Fresno Slough, wells & C.V.P.	48,043	20,102	2.39	67,460	20,220	3.34	61,195	19,422	3.15	70,000	18,404	3.80	76,641	20,843	3.79	60,456	18,195	3.76	57,442	15,340	2.98	48,318	16,917	2.86	--	--	--	--	--	--		
Laguna	Kings River & wells	38,823	26,878	1.48	51,000	34,000	1.50	61,891	34,000	1.80	7,000	25,000	.68	25,019	--	--	50,618	25,309	2.00	--	--	--	--	--	--	--	--	--	--	--	--		
Landowners	Wells & C.V.P.	44,468	23,507	1.89	48,239	24,969	1.93	46,887	23,972	1.96	58,082	24,133	2.16	47,640	24,842	1.96	44,070	25,149	1.75	34,653	23,538	1.47	--	--	--	--	--	--	--	--	--		
Lindsay-Stratton	Kaweah River, wells & C.V.P.	23,380	11,758	1.99	24,119	11,087	2.18	28,287	10,854	2.05	23,615	10,459	2.26	28,688	10,513	2.15	19,662	9,988	1.96	17,405	9,581	1.83	19,117	9,465	2.02	--	--	--	--	--	--		
Lower Tule	Dale River & C.V.P.	111,766	80,163	1.39	124,158	77,722	1.60	108,706	79,852	1.36	101,606	81,107	1.25	89,056	75,051	1.89	90,000	77,848	1.16	76,000	77,661	.98	40,000	60,436	.66	--	--	--	--	--	--		
Madura	Fresno River & C.V.P.	87,007	85,873	1.03	82,836	87,534	.95	73,789	91,094	.81	60,958	91,679	.66	47,639	91,031	.52	48,413	91,223	.46	46,862	85,240	.55	18,046	88,688	2.03	--	--	--	--	--	--		
Merced	Merced River & wells	461,800	195,997	4.36	508,000	111,445	4.50	500,900	112,283	4.46	443,550	110,263	4.02	440,250	106,814	4.12	514,200	106,945	4.72	426,700	113,408	3.76	445,800	115,531	3.06	--	--	--	--	--	--		
Modesto	Toultome River & wells	215,100	123,982	1.72	246,300	67,361	3.63	246,300	67,370	3.60	247,100	77,114	3.20	263,900	79,137	3.33	258,550	76,108	3.40	289,900	76,594	3.00	245,670	68,918	3.56	--	--	--	--	--	--		
Porterville	Tule River & C.V.P.	5,395	3,988	.41	5,940	15,389	.29	5,979	13,980	.28	4,030	14,612	.27	2,738	18,247	.19	5,504	16,030	.37	4,137	14,410	.29	4,110	14,511	.29	--	--	--	--	--	--		
Riverdale	Dale River	49,834	10,350	4.81	10,778	10,460	1.03	42,848	11,950	3.62	34,000	18,990	2.62	35,000	18,990	2.71	47,500	18,000	3.96	25,000	13,380	1.87	--	--	--	--	--	--	--	--	--		
Trinity	Fresno River	35,838	5,231	6.85	34,696	7,581	4.58	34,139	8,845	3.86	33,915	8,899	4.09	45,343	9,341	4.96	46,082	8,674	5.30	43,751	8,001	5.47	40,698	8,112	5.02	--	--	--	--	--	--		
Tulare	Kaweah River & wells	131,610	68,509	2.10	95,557	64,069	1.49	117,500	66,349	1.77	100,000	65,082	1.54	99,157	64,692	1.53	158,771	67,465	2.35	--	--	--	--	--	--	--	--	--	--	--	--		
Turlock	Toultome River & C.V.P.	442,301	162,439	2.72	512,932	161,899	3.17	491,826	161,462	3.05	441,820	181,147	2.44	487,869	187,454	2.60	505,580	181,808	2.78	454,754	182,536	2.49	461,692	173,731	2.64	--	--	--	--	--	--		
Waterford	Toultome River	39,395	6,837	4.14	35,460	6,952	4.67	39,403	6,910	5.12	39,562	7,172	4.12	33,991	7,368	4.61	35,393	6,969	5.06	35,064	6,815	5.14	38,785	6,700	4.89	--	--	--	--	--	--		
Westside	San Joaquin River, wells & C.V.P.	88,937	9,232	3.43	38,265	9,647	3.91	39,635	9,827	3.80	39,143	10,881	2.95	39,053	10,933	2.66	39,590	10,334	2.81	24,159	10,904	2.22	26,844	12,800	2.08	--	--	--	--	--	--		
West Stanislaus	San Joaquin River, wells & C.V.P.	58,067	23,471	2.47	77,216	23,288	3.32	69,307	23,344	2.97	68,994	23,639	2.92	68,983	24,633	2.80	78,474	23,868	3.04	59,993	24,495	2.45	66,642	24,862	2.68	--	--	--	--	--	--		

a/ Prior to 1956, it was not possible to separate out double crop acreage from the crop report.

Source: Report on Irrigation and Water Storage Districts in California for 1951-1955 and 1956-1958. Bulletin 21, California State Department of Water Resources.

Investment

Investments in the distribution system for delivering water to farm headgates is one of the most important factors affecting the cost of water to farmers. The magnitude of such investments varies, in turn, according to design and construction methods. Distribution systems may range from unlined ditches to reinforced concrete pipelines delivering water under pressure to farm headgates. Water losses are high in unlined ditches, due to seepage and evaporation. Total losses for some distribution systems may exceed 50 percent, according to considered estimates. Seepage losses are not complete losses, of course, if the water percolates down to recharge underground basins. If, however, an imperious soil layer lies close to the surface of the ground these seepage losses can create severe drainage problems.

Concrete pipeline or concrete-lined ditches reduce seepage losses considerably, but are very costly. In spite of the cost element, however, and even where drainage problems do not exist, distributing agencies are using pipelines and lined canals increasingly during recent years. Thus, they substitute capital resources for the more expensive water resource, the result is to increase fixed costs, but to save the variable costs represented by lost water.

A second factor affecting distribution system cost is the size of the service area per turnout. If a distribution system is designed for delivering water to each 40-acre parcel of land in a district, it will require many more miles of ditches or pipeline than a system delivering water to each 160-acre area. A comparison of California districts underscores this point. Two irrigation distribution systems constructed during the 1950-1960 period with each turnout serving

^{1/} Many excellent articles and bulletins have been written on this subject. For a few examples, see Brewer, M. F., Water Pricing and Allocation with Particular Reference to California Irrigation Districts, Berkeley: University of California, Agr. Exp. Sta., Giannini Foundation Mimeo. Rept. No. 235, October 1960, and Economics of Public Water Pricing, Giannini Foundation Research Rept. No. 244, May 1961.

160 acres report investments per-acre-served of about \$130 and \$185, respectively. These were closed type systems with a capacity of one cubic foot per second for each 75-80 acres. In contrast, two other systems built during the same period with turnouts for each 80 acres, and the same capacities, invested about \$250 and \$280 per acre served. Such wide differences should not always be expected. Other cost-affecting elements, such as construction methods and materials, topography, and right-of-way costs, might offset or widen them. These examples do give some indication of how variations in the ratio of turnouts to area, affect the magnitude of costs involved.

Irrigation districts and other distributing agencies perform services other than delivering water to farm headgates. Some organizations have developed expensive drainage facilities for all or parts of their service areas. This service may involve constructing drains, deepening ditches, building and operating pumps to carry off excess water accumulating at lower elevations. Other services include constructing and operating water spreading facilities, generating and distributing electrical power, and providing telephone service.

Irrigation districts and other organizations holding contracts with the agency pay the U. S. Bureau of Reclamation for water they obtain from this source. Long-term contractors pay \$3.50 per acre-foot for Class I water from the Friant-Kern and Madera canals. The price for Class II water is \$1.50 per acre-foot. Class I water represents the basic or firm water supply and Class II the surplus. Each water sales contract specified minimum quantities of each class that the contractor must take if this water is available. Distributing agencies taking irrigation water from the Delta-Mendota Canal pay a canal-side price of \$3.50 per acre-foot for any and all water.

Operating Costs

Operating costs for irrigation districts vary widely. Administrative, operating and maintenance costs, in a sample of 21 irrigation districts, ranged from \$0.94 to \$7.76 per acre-foot for water delivered to farm headgates. To make

the comparison as direct as possible, pumping costs and outlays for purchased water are not included in these figures. The mean cost per acre-foot delivered was \$1.81.

The smaller districts in terms of water delivered usually had the highest costs, while the districts delivering the larger quantities of water generally showed lower costs. These quantities of water delivered do not include water spread by the districts for recharging underground basins.

Our cross section sample of irrigation districts is not sufficiently homogeneous to support statistically significant generalizations as to how size relates to costs in distributing surface irrigation water (see Table 12). Operating expenses for irrigation districts with unlined canals and laterals differ widely from districts with completely closed concrete pipelines. Also, some of these districts operate drainage facilities for parts of their service areas, whereas others do not. A multiple regression equation fitted to these data with cost per-acre-foot as the dependent, and gross service area and total water delivered as the independent variables, did not explain a significant amount of the cost variations.

How Suppliers Price Water

Agencies supplying irrigation water may levy charges and obtain revenue to cover their costs in various ways. The law prescribes or delimits the methods that some distributing agencies may use. Irrigation districts, for example, have the power as public entities to issue bonds and to assess and collect taxes on land. The law does not give this power to private water companies, or to mutual water companies. Private water companies come under the Public Utilities Commission, and usually use a metered toll rate. Mutual water companies generally collect their revenue from assessments on stock in the company; sometimes they use a metered toll in addition.

TABLE 12

Operating Expense for Irrigation Districts, 1958

District	Gross service area in acres	Admin.	Wages	Mat.	Other	Total Cost	Water delivered acre feet	Cost per acre foot
	1	2	3	4	5	6	7	8
Alpaugh	8,131	14,652	18,120	6,856	19,135	58,763	7,573	7.76
Alta	129,300	91,989	91,332	30,461	119,327	333,109	185,045	1.80
Central								
California	154,100	94,464	191,268	93,932	63,190	442,854	377,454	1.17
Consolidated	155,000	72,666	90,899	24,801	122,893	311,259	330,892	.94
Corcoran	51,600	11,788	44,512	76,516	55,934	188,750	54,039	3.49
Delano-								
Barliment	56,594	29,072	43,200	14,708	85,033	172,013	151,834	1.13
Exeter	14,638	34,007	13,686	10,499	15,897	73,888	22,538	3.28
Fresno	235,520	161,819	403,134	72,095	303,314	637,048	417,138	1.53
Ivanhoe	10,887	26,573	12,416	389	4,937	44,315	14,707	3.01
James	25,836	32,112	33,466	34,951	13,386	113,915	48,043	2.37
Lindmore	27,267	44,402	58,881	15,945	--	119,228	44,468	2.68
Lindsay-								
Strathmore	15,440	28,449	64,898	44,682	41,974	180,003	23,380	7.70
Lower Tule	103,087	53,089	40,687	10,287	66,397	170,460	111,766	1.52
Madera	112,250	96,893	114,506	52,539	2,527	266,465	87,007	3.06
Merced	163,384	181,632	426,781	178,973	127,915	915,301	461,800	1.98
Porterville	17,127	22,155	3,663	349	3,578	29,745	5,385	5.52
Saucelito	19,326	16,167	10,938	455	--	27,560	18,030	1.53
Shafter-								
Wasco	37,528	40,116	23,725	2,366	4,193	70,400	32,918	2.14
Tranquility	10,750	22,815	19,224	9,449	36,964	86,452	35,838	2.41
Tulare	75,121	47,950	102,280	81,412	1,178	232,820	131,610	1.77
W. Stanislaus	22,429	21,854	111,135	60,320	11,190	204,499	58,067	3.52
TOTAL						4,678,847	2,619,532	1.78

Source: Annual Report of Financial Transactions Concerning Irrigation Districts of California, 1958; and California Department of Water Resources, Bul. 21, Report on Irrigation and Water Storage Districts in California for 1956-1958, March 1960.

Irrigation districts, the agencies delivering the larger quantity of all water, use a variety of methods to obtain revenue. Most common among these is a tax assessment combined with a metered toll charge; many use only the assessment. Some districts levy a flat rate per acre of crops irrigated, varying the rate according to crops grown.

Some irrigation districts vary metered toll rates within their service areas. Those with portions of their service areas significantly higher in elevation than the source of supply may charge higher toll rates in such localities to cover added costs for lifting the water to the higher elevations.

Annual assessments per acre also may vary within a district, even for land of uniform valuation. Such variations in levy on uniform quality land may be applied in some parts of a district to recover the costs for local drainage or canal improvements.

If we impute a water user's total payments as costs for direct deliveries of irrigation water, the result is to mask the cost and value of other services that the distributing agency provides. Thus the agency may spread water or operate drainage facilities with important benefits to the water user, and look to these payments for reimbursement.

A farmer within an irrigation district may regard the annual assessment portion of the total cost for surface water as a fixed cost. He must pay this amount even though he receives no water during the year. This fixed portion reacts sharply on the average total cost per acre-foot of water when year-to-year quantities fluctuate, as between wet and dry years. This fixed portion of the total cost must be spread over relatively fewer acre-feet per acre delivered in years of short supply.

The metered toll rate, if used, represents the variable cost portion of the total payment complex; the purchaser pays it only when the agency delivers water.

Data available for 11 irrigation districts are helpful as indicators of how variations in annual water deliveries affect average total costs to users (see Table 13). We selected these districts according to geographic location, and because data were available regarding their operations; we do not consider them a representative sample. The water delivery data include the wet year, 1957-1958, (annual runoff about 125 percent of normal) and the dry year, 1953-1954 (annual runoff about 75 percent of normal).

An irrigation district does not always reduce the quantities of water that it delivers to its users within the district during a dry year, as compared with a wet one (see Table 13). A particular district may have sufficient storage carryover from the previous year to meet needs in a dry year, or it may divert water from its normal ground water recharge program and use it to maintain or increase direct irrigation deliveries.

TABLE 13

Quantity and Cost of Surface Irrigation Water Delivered in Wet and Dry Years
for 11 Irrigation Districts; San Joaquin Valley Cotton Area

District	Assessment per \$100 valuation	Typical valuation per acre	Assessment per acre	Average delivery per irr. acre		Average assessment per acre-foot (fixed cost)		Typical toll rate per ac. ft. (variable cost)	Total cost per ac. ft.	
				Wet year	Dry year	Wet year	Dry year		Wet year	Dry year
		dollars		acre feet		dollars				
1	4.25	100.00	4.25	1.90	.87	2.24	4.83	0	2.24	4.88
2	4.00	100.00	4.00	3.50	1.51	1.14	2.65	0	1.14	2.65
3	1.50	100.00	1.50	1.23	1.29	1.22	1.16	5.50	6.72	6.66
4	7.00	140.00	9.80	3.08	2.82	3.18	3.48	2.00	5.18	5.48
5	3.25	50.00	1.62	2.39	3.80	.68	.43	4.50	5.18	4.93
6	5.00	100.00	5.00	2.47	2.13	2.02	2.35	0	2.02	2.35
7	3.16	200.00	6.32	1.86	2.16	3.40	2.92	5.00	8.40	7.92
8	5.70	110.00	6.27	1.39	1.25	4.51	5.02	3.00	7.51	8.02
9	3.86	115.00	4.44	1.00	.66	4.44	6.73	2.60	7.04	9.33
10	3.50	100.00	3.50	1.36	1.56	2.57	2.24	4.50	7.07	6.74
11	6.50	100.00	6.50	2.04	1.54	3.19	4.22	2.00	5.19	6.22

Source: Report on Irrigation in Water Storage Districts in California, California Department of Water Resources, Bulletin 21 and Survey of Irrigation Districts.

APPENDIX TABLE 1

Schedules for Electrical Energy Rates

A. Pacific Gas and Electric^{a/}

Connected load horsepower	Energy charge in addition to the service charge rate per kwh. for consumptions per hp. per year of			
	Annual service charge per hp.	First 1000 kwh.	Next 1000 kwh.	All over 2000 kwh.
	dollars		cents	
2 to 4.9 ^{b/}	8.83	1.85	.91	.65
5 to 14.9	7.46	1.59	.91	.65
15 to 49.9	6.73	1.49	.91	.65
50 to 99.9	5.99	1.38	.91	.59
100 to 249.9	5.26	1.33	.91	.59
250 to 499.9	5.26	1.28	.91	.59
500 to 999.9	5.05	1.22	.91	.59
1000 to 2499.9	4.73	1.22	.91	.59
2500 and over	4.20	1.22	.91	.59

B. Southern California Edison^{c/}

2 to 4.9	9.00	1.86	.82	.64
5 to 14.9	8.00	1.66	.82	.64
15 to 49.9	7.50	1.56	.82	.64
50 to 99.9	7.00	1.46	.82	.64
100 and over	6.50	1.36	.82	.64

Minimum charge: The annual minimum charge shall be the annual service charge.

^{a/} Revised Cal. P.U.C. Sheet No. 2891-E.

^{b/} In no case will the total annual service charge nor the energy charge be based on less than 2 hp. for single-phase service, nor less than 3 hp. for three-phase service.

^{c/} Revised Cal. P.U.C. Sheet No. 2811-E.